Interpretation of Groundwater Velocities from Heat-Based Flow Sensors

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RESEARCH OBJECTIVES

Heterogeneities in formation properties around an *in situ* heat-based flow sensor may lead to incorrect interpretations of groundwater flow velocities. The flow sensor operates by constant heating of a 0.75 m long, 5 cm diameter cylindrical probe, which contains 30 thermistors in contact with the formation. The temperature evolution at each thermistor is inverted to obtain an estimate of the groundwater flow velocity vector, based on the assumption that the formation is homogeneous. Analysis of data from three heat-based flow sensors installed in a shallow sand aquifer at the Former Fort Ord Army Base near Monterey, California, suggested a strong and unexpected component of downward flow. Three-dimensional TOUGH2 simulations were conducted to investigate how differences in the thermal conductivity and permeability around the instrument may lead to inaccurate indications of downward flow velocities.

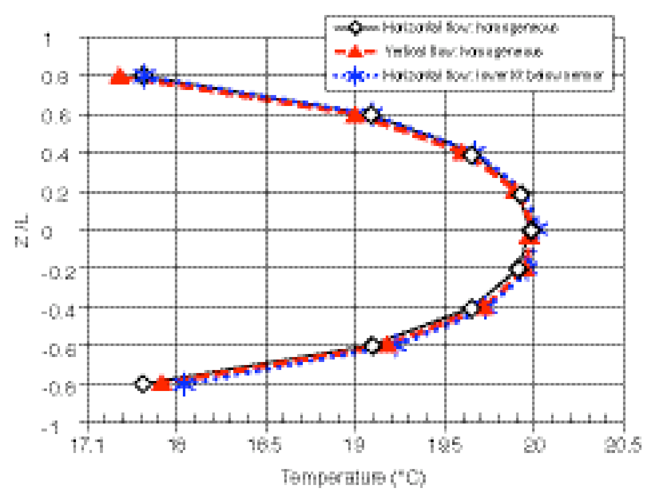

Figure 1. Simulated temperature profiles along the sensor for horizontal and vertical flow in a homogeneous formation, and for horizontal flow when K_t below the sensor is lower than K_t along the sensor

APPROACH

Conformal mapping was used to generate a discretization highly refined near the cylindrical instrument body to use for simulating flow and heat transport near the sensor. A 17-layer model was used in the 3-D simulations, with the heated portion of the flow sensor represented by the nine center layers. Horizontal flow was imposed across the domain in all the simulations, except for one where vertical flow was imposed. Heterogeneity was assumed only in the vertical direction, resulting in a "layer-cake" type stratigraphy.

ACCOMPLISHMENTS

Simulated temperature profiles on the downstream side of the flow sensor are plotted as a function of depth in Figure 1. In a homogeneous formation, the temperature profile is symmetric for horizontal flow, while higher temperatures are observed along the bottom half of the sensor relative to the top half for vertical (downward) flow. When the thermal conductivity (K_t) of the formation is lower below the sensor compared to the thermal conductivity along the length of the sensor (2.1 versus 1.8 W/m°C), the temperature profile becomes shifted in such a manner that it could be interpreted as resulting from downward flow, even though flow is actually horizontal. A decrease in the permeability towards the bottom of the sensor relative to the top can also result in a temperature profile that could be interpreted as having a downward flow component, although the effect tends to be smaller.

SIGNIFICANCE OF FINDINGS

The simulations demonstrate that the temperatures recorded by heat-based flow sensors are sensitive to differences in the thermal and hydraulic properties of the formation. Under conditions of strictly horizontal flow, the temperature profile along the length of the sensor can be perturbed by changes in the thermal conductivity and permeability, such that analysis of the data assuming homogeneous formation properties could result in interpreting the temperature shift as the result of downward flow.

RELATED PUBLICATIONS

Su, G.W., B.M. Freifeld, C.M. Oldenburg, P.D. Jordan, and P.F. Daley, Simulation of *in situ* permeable flow sensors for measuring groundwater velocity. Ground Water (in review), 2005. Berkeley Lab Report LBNL-57084.

Jordan, P.D., C.M. Oldenburg, and G.W. Su, Analysis of aquifer response, groundwater flow, and plume evolution at Site OU1, Former Fort Ord, California. Berkeley Lab Report LBNL-57251, 2005.

ACKNOWLEDGMENTS

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